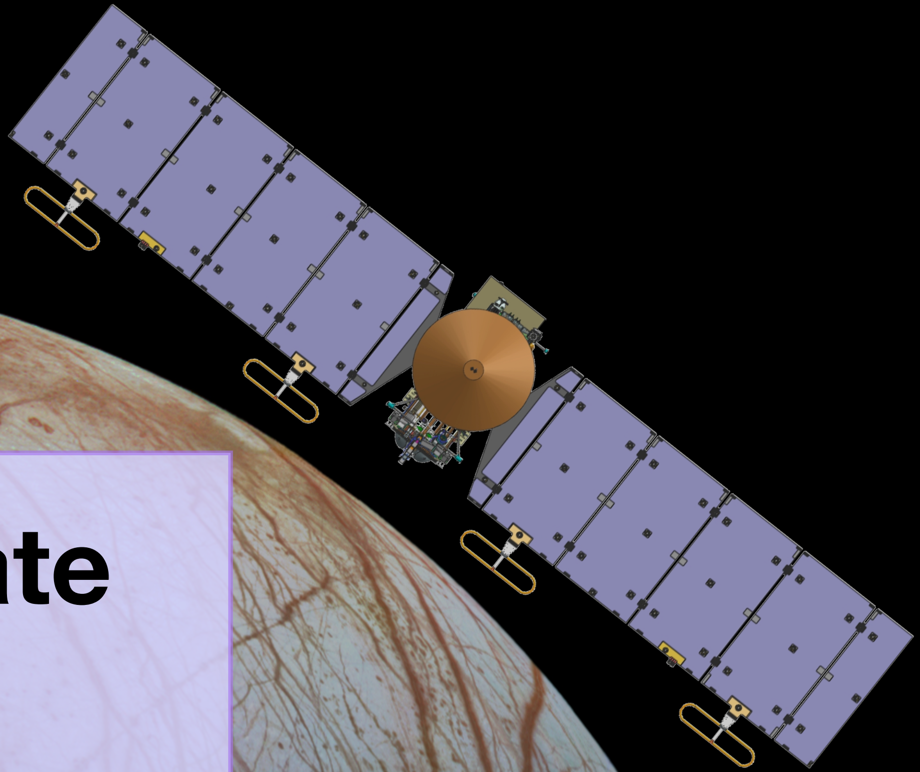


Europa Clipper Mission Update

Maddalena Jackson

Todd Bayer, Molly Bittner, Brent Buffington, Gregory Dubos, Eric Ferguson, Ian Harris, Maddalena Jackson, Gene Lee, Kari Lewis, Jason Kastner, Ron Morillo, Ramiro Perez, Mana Salami, Joel Signorelli, Oleg Sindiy, Brett Smith, Melissa Soriano
Jet Propulsion Laboratory,
California Institute of Technology

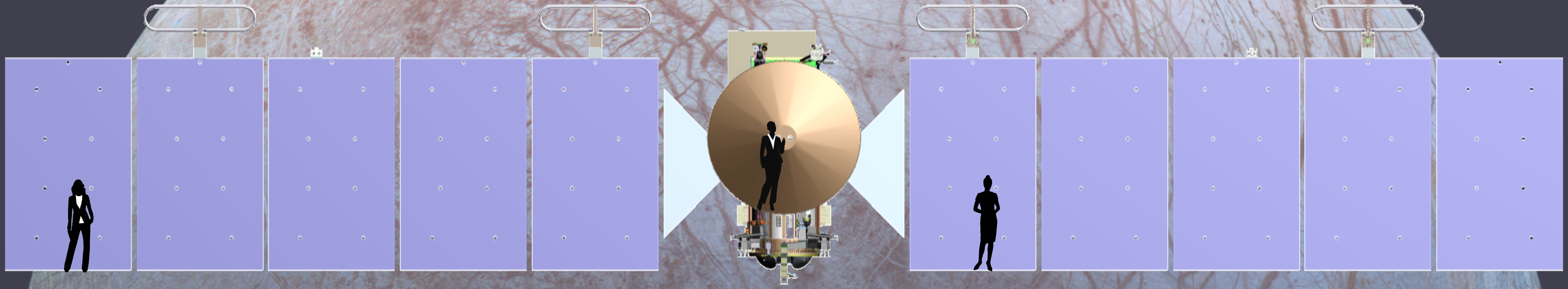
Karen Kirby, Nori Laslo
Johns Hopkins University
Applied Physics Laboratory

Europa Clipper Mission: Overview

Topics
- Mission Recap
- Mission Challenges
- Mission Status
- Selected Updates
- Future Work

The Mission
Destination: Europa, Moon of Jupiter
Launch Date: June, 2023
Travel Time: ~3 or ~6 years
Instruments: 9
Mass: ~4600 kg (~2500 kg unfueled)
Purpose: Assess the potential habitability

The Target
Name: Europa
Location: Orbiting Jupiter
Distance: ~5 – 5.5 AU
Size: slightly smaller than Earth's Moon
Supports Life: unknown



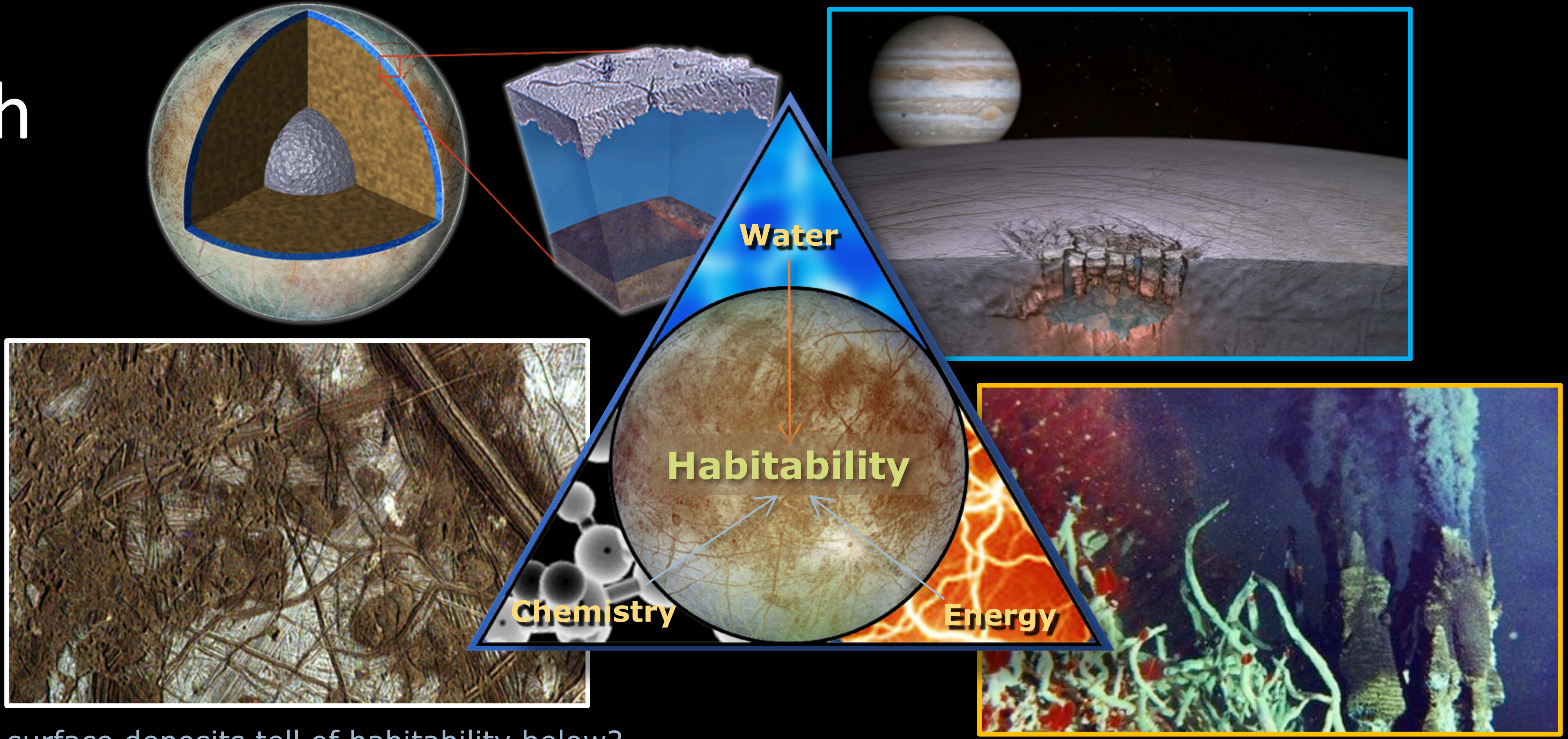
The Spacecraft

WHY

Why Investigate Europa?

The Search for Life

Water: Are a global ocean and lakes of water hidden below the ice?



Chemistry: Do red surface deposits tell of habitability below?

Energy: Can chemical disequilibrium provide energy for life?

HOW

The Europa Clipper Instruments

Payload specifically designed to assess habitability

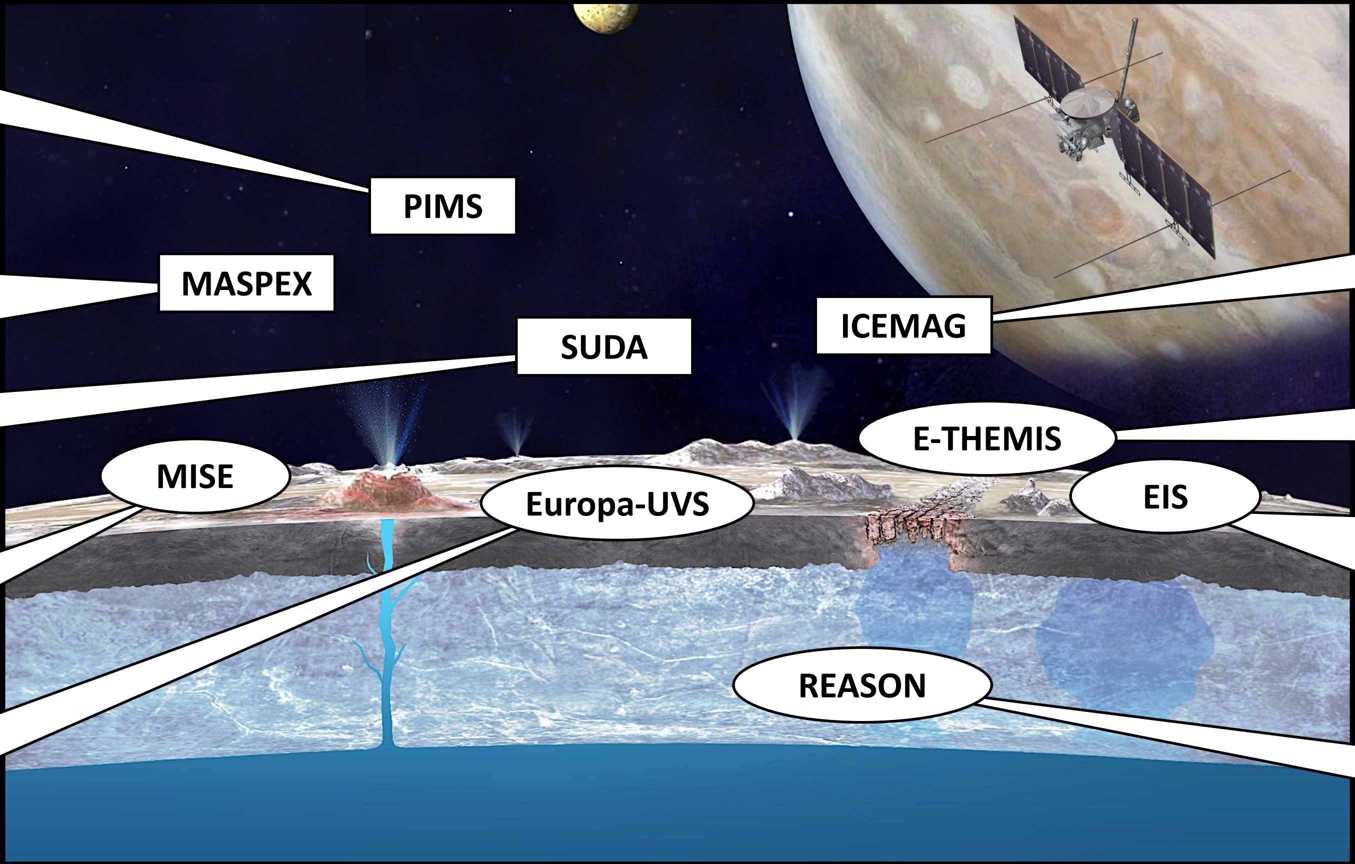
PIMS
Faraday Cups
plasma environment

MASPEX
Mass Spectrometer
sniffing atmospheric composition

SUDA
Dust Analyzer
surface & plume composition

MISE
IR Spectrometer
surface chemical fingerprints

Europa-UVS
UV Spectrograph
surface & plume/atmosphere composition



In Situ

Remote Sensing

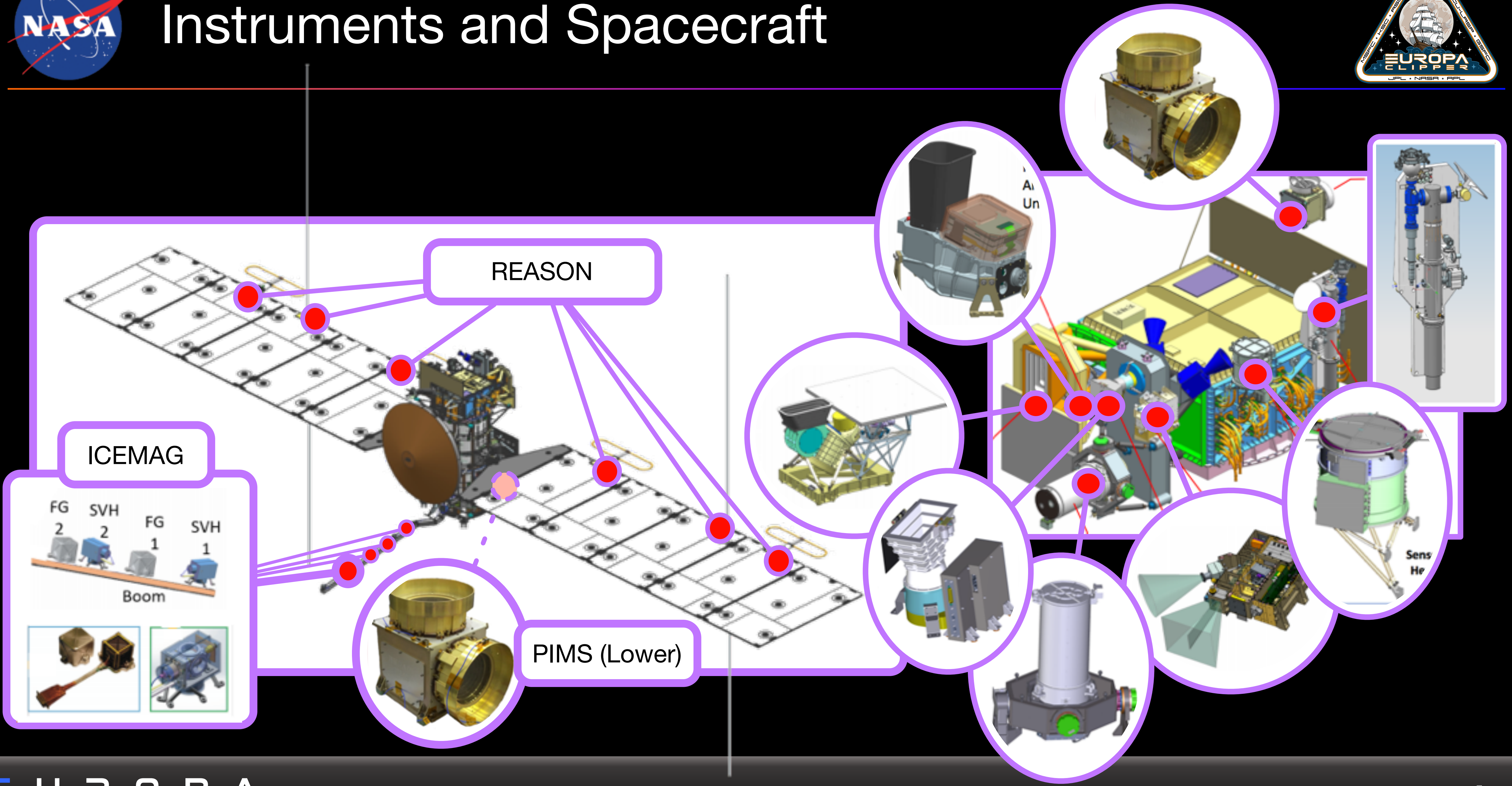
ICEMAG
Magnetometer
sensing ocean properties

E-THEMIS
Thermal Imager
searching for hot spots

EIS
Narrow-Angle Camera + Wide-Angle Camera
mapping alien landscape in 3D & color

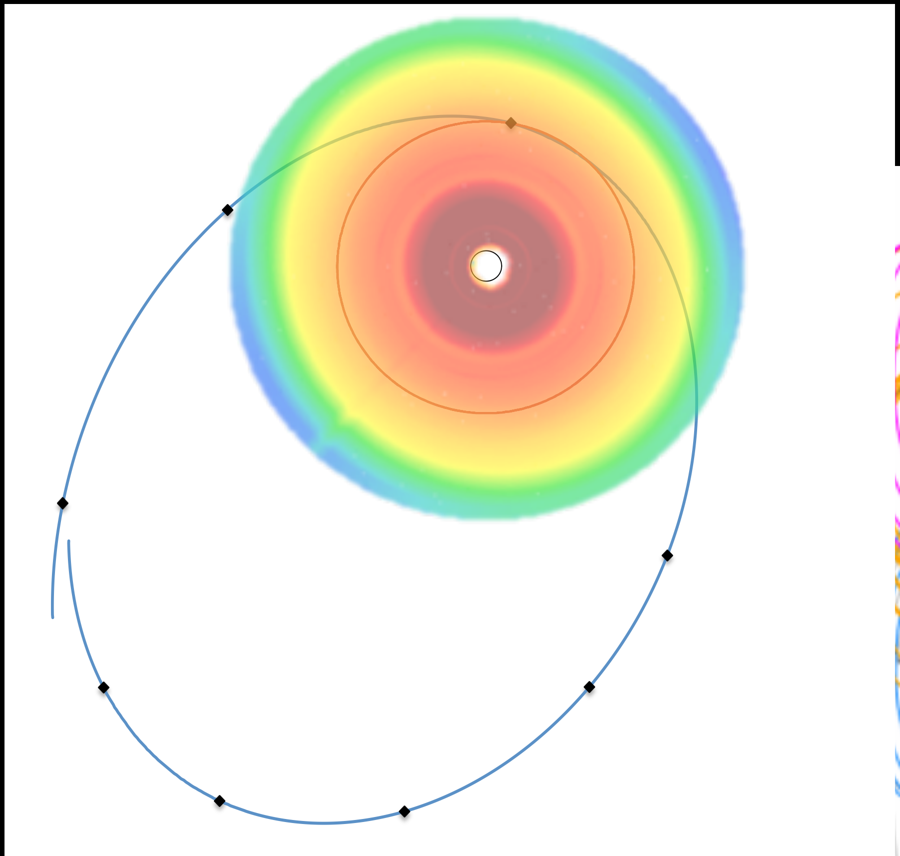
REASON
Ice-Penetrating Radar
plumbing the ice shell

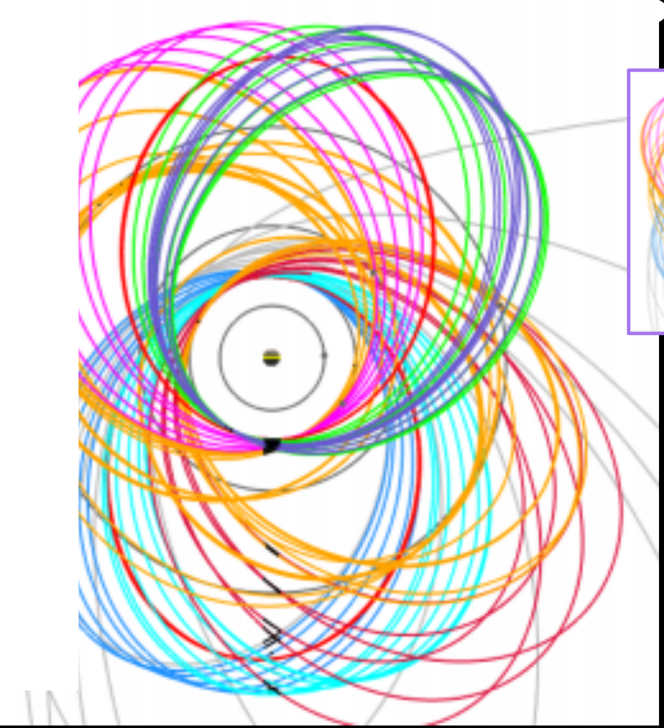
Instruments and Spacecraft



CHALLENGES

Challenge: Radiation

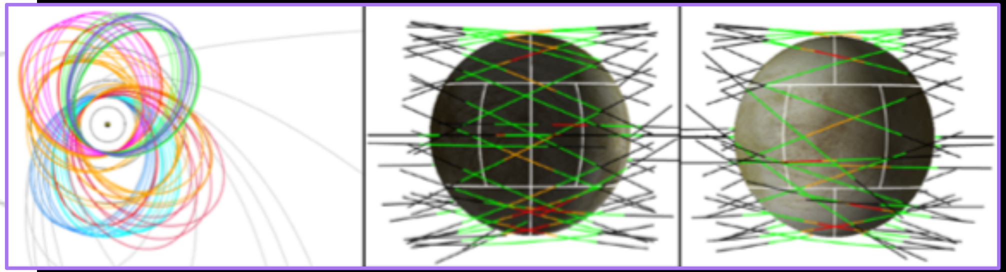


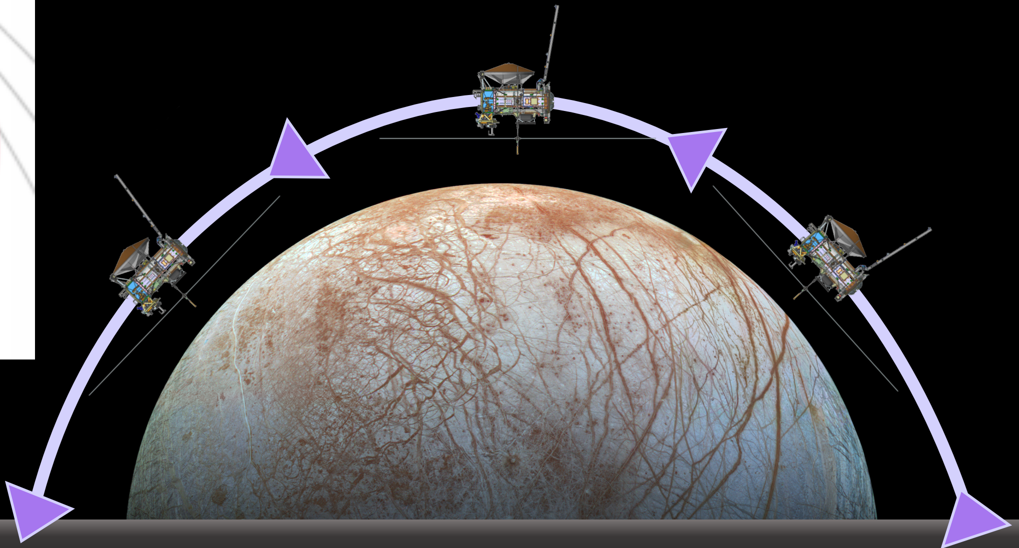


Strategy 1: Radiation-tolerant parts

Strategy 2: Vault (shields electronics)

Strategy 3: Flyby trajectory design



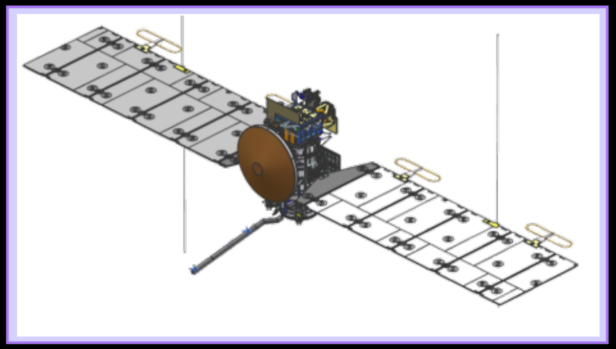


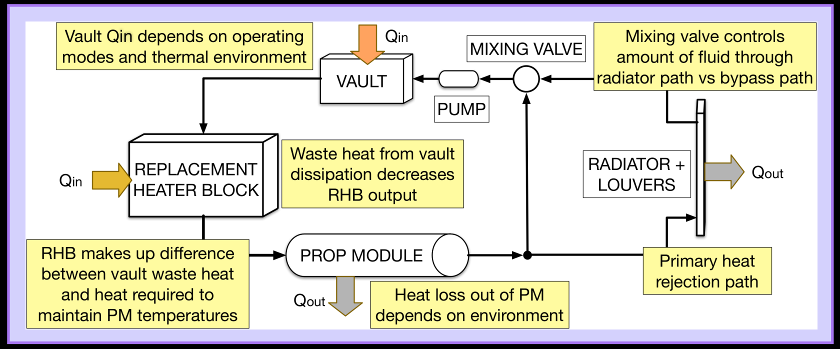
Challenge: Thermal Extremes & Multiple LVs

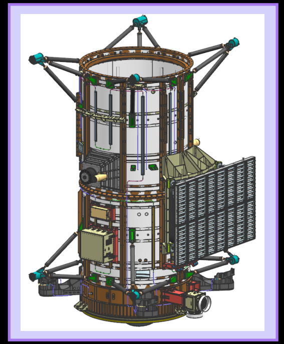
- Hot: possible inner cruise
- Cold: Jupiter + 9-hour Eclipse

- Solar mission
- Multiple LV = Different dynamic, shock, and acoustic environments

- Design for enveloping worst case (plus margin)
- Optimized Thermal Architecture
  - Reuse waste electronics heat
  - Pumped fluid loop transports waste heat
  - Radiator and sun shade for possible inner cruise

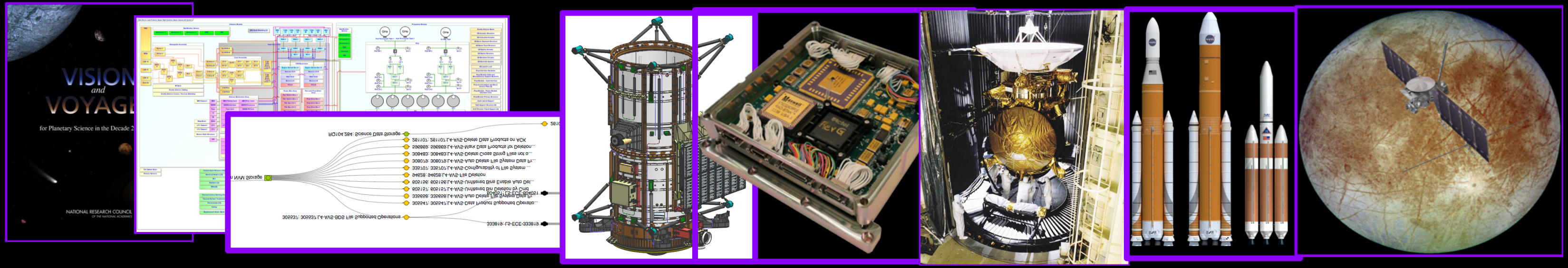






PROJECT STATUS

Where are we now



Jan 2014 - Jun 2015 Pre-Phase A	Jun 2015 - Feb 2017 Phase A	Feb 2017 - Oct 2018 Phase B	Oct 2018 - Dec 2020 Phase C	Dec 2020 - Jun 2022 Phase D
Jan 2014 - Jun 2015 Pre-Phase A	Jun 2015 - Feb 2017 Phase A	Feb 2017 - Jun 2019 Phase B	Jun 2019 — Phase C	— Jun 2023 Phase D
Formulation			Implementation	

- Directed to work to 2023 Launch Date
- Replanning exercises
- Instrument schedules unchanged

Feb 2017 - Jun 2019 Phase B	Jun 2019 —Phase C

Project PDR

SA PDR

Delta SA PDR

IWR

Instrument CDRs

Subsystem CDRs

FS CDR

Project CDR

Some Project Status

Feb 2017 - Jun 2019 Phase B	Jun 2019 —Phase C

Safety

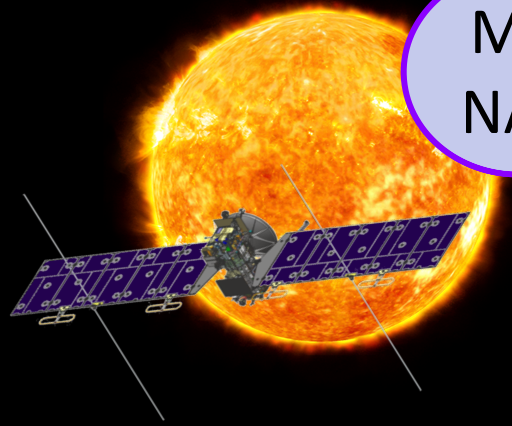
LV

PP

V&V

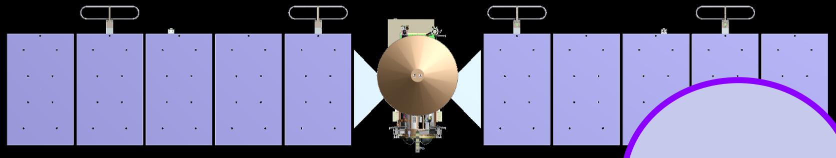
Systems

MD
NAV



SI&T

MOS &
GDS

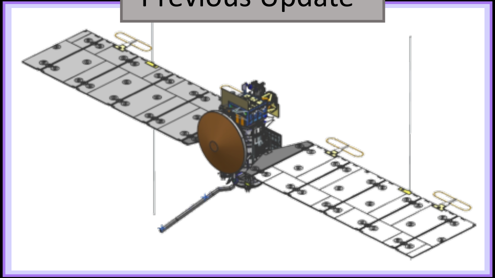


FS

FS UPDATES

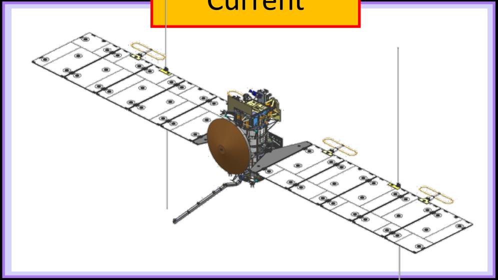
Selected FS Updates

Previous Update



- 2550 kg FS Dry mass
- Payload Mass (Alloc): 380 kg
- 348 Ah Battery
- 86 m^2 Solar Array area
- 5.1 TB Downlink capability

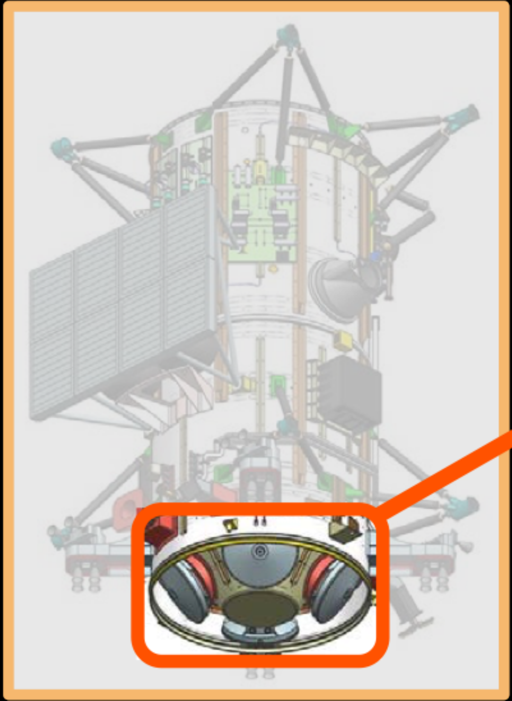
Current

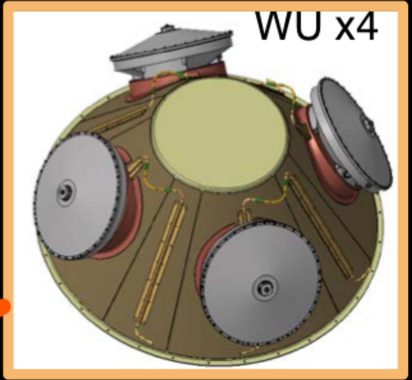


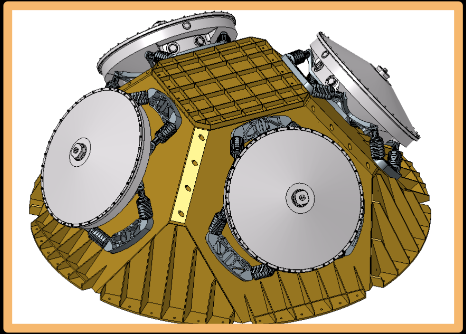
- 2670 kg FS Dry mass
- Payload Mass (Alloc): 408 kg
- 348 Ah Battery
- 102 m^2 Solar Array area
- 5.3 TB Downlink capability

- CM Offset Trade
- EIS Gimbal System Update
- PIMS Cover Removal
- SLS Block 1B Removal
- PIMS Electronics Move
- EIS Cross-Strapping Removal
- MISE Bipod to Frame
- 2 PSSs added; last thermostats removed (on prop module)

- RWA Isolators Added
- REASON heaters removed
- ICEMAG Heater Services Added
- E-THEMIS Radiator Design
- MASPEX & SUDA Swap
- Vault Configuration Updates
- Third LGA Added for Launch
- SSIRU Trade (1 vs 2)
- ICEMAG Electronics Location Trade







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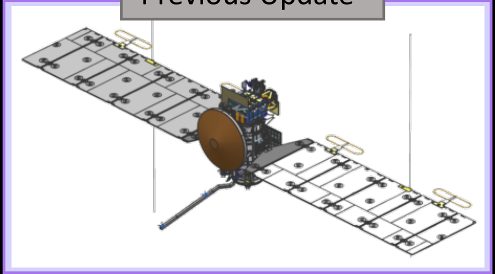

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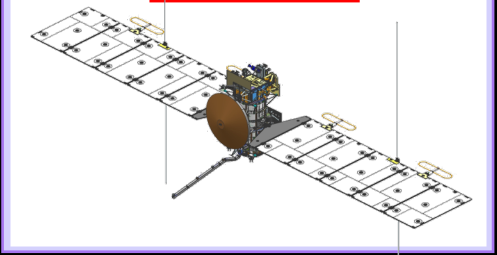

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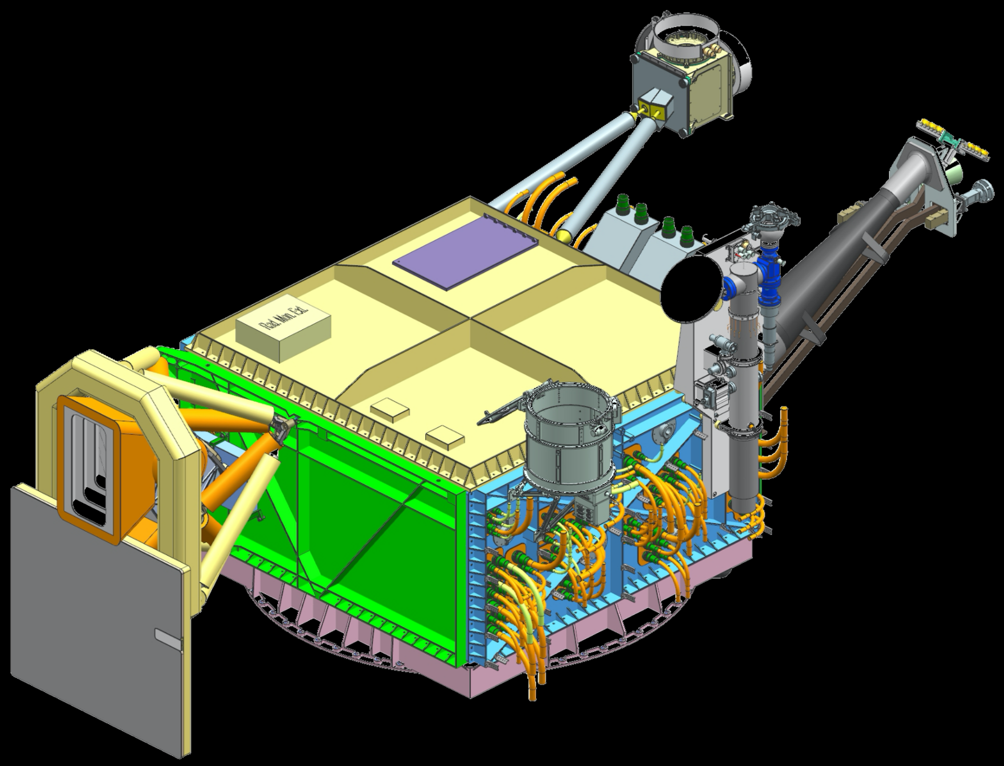

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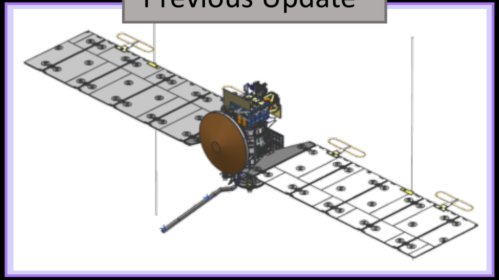

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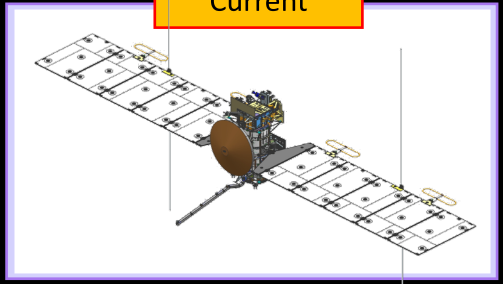

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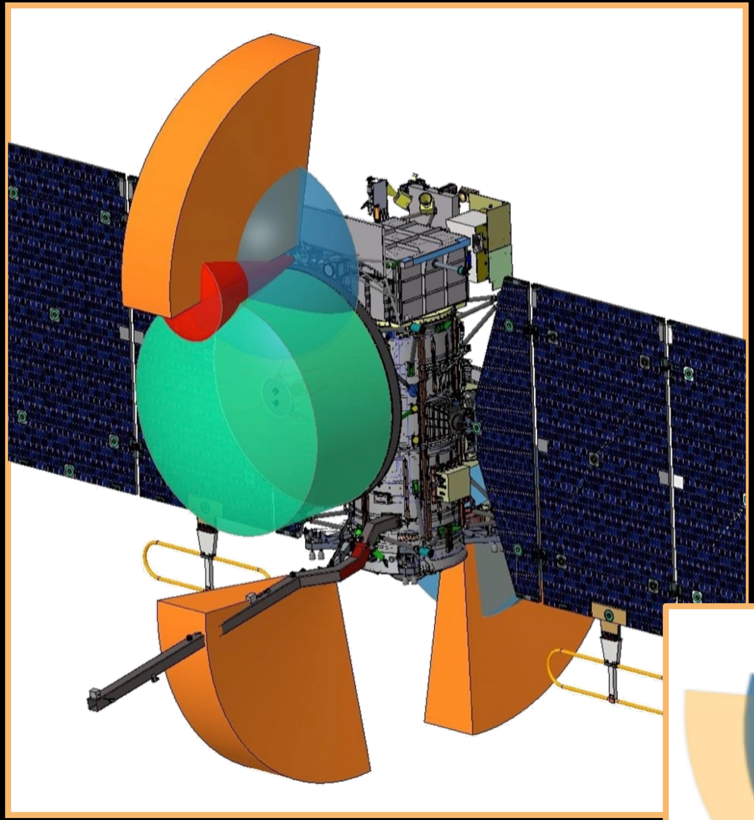

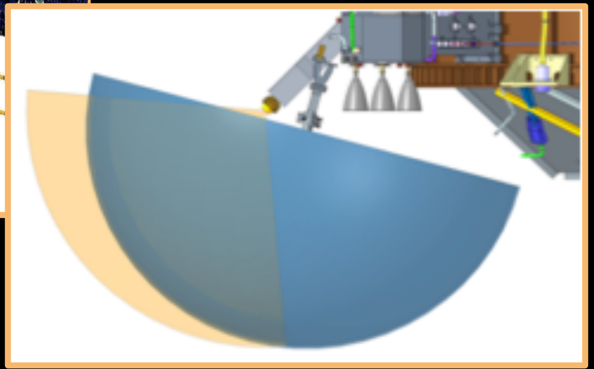

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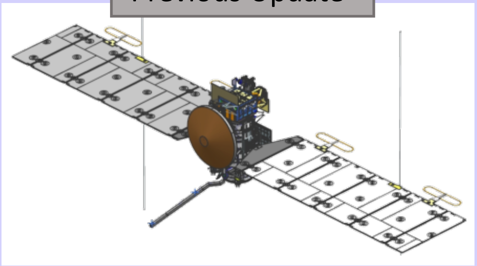

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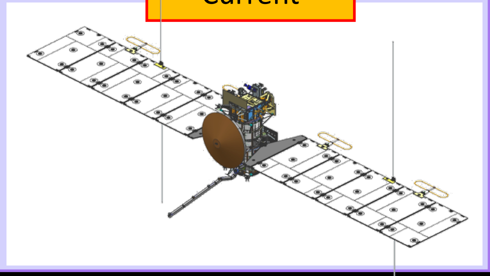

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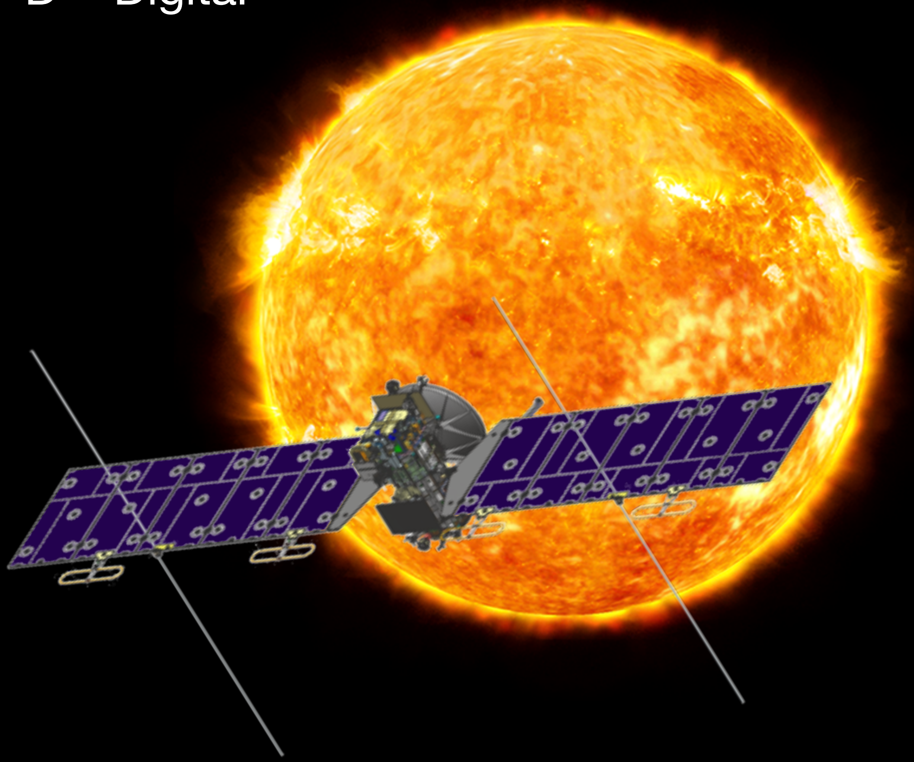
✅ 👍

Trade: CSS/DSS (1)

"SS" = Sun Sensor
C = Coarse
D = Digital

- Primarily use SRUs and SSIRUs for attitude estimation
- Sun sensors: launch, sanity check, during specific faults



- Fault Protection: *Don't have problems. But if there is a problem, get to a power-positive, thermally safe state and phone home*
- Thermal & Telecom need accurate pointing in this situation (Thermal: don't get too hot; Telecom: sufficient comms rates)
- Power & Thermal need "fast" recovery (Thermal: don't overheat; Power: don't drain the battery before becoming power positive again)

Sunsearch

How fast can we find the sun
How fast can we point to it
Don't point sensitive elements at the sun
When we get there: how accurately can we stay sun pointed

Sunpoint

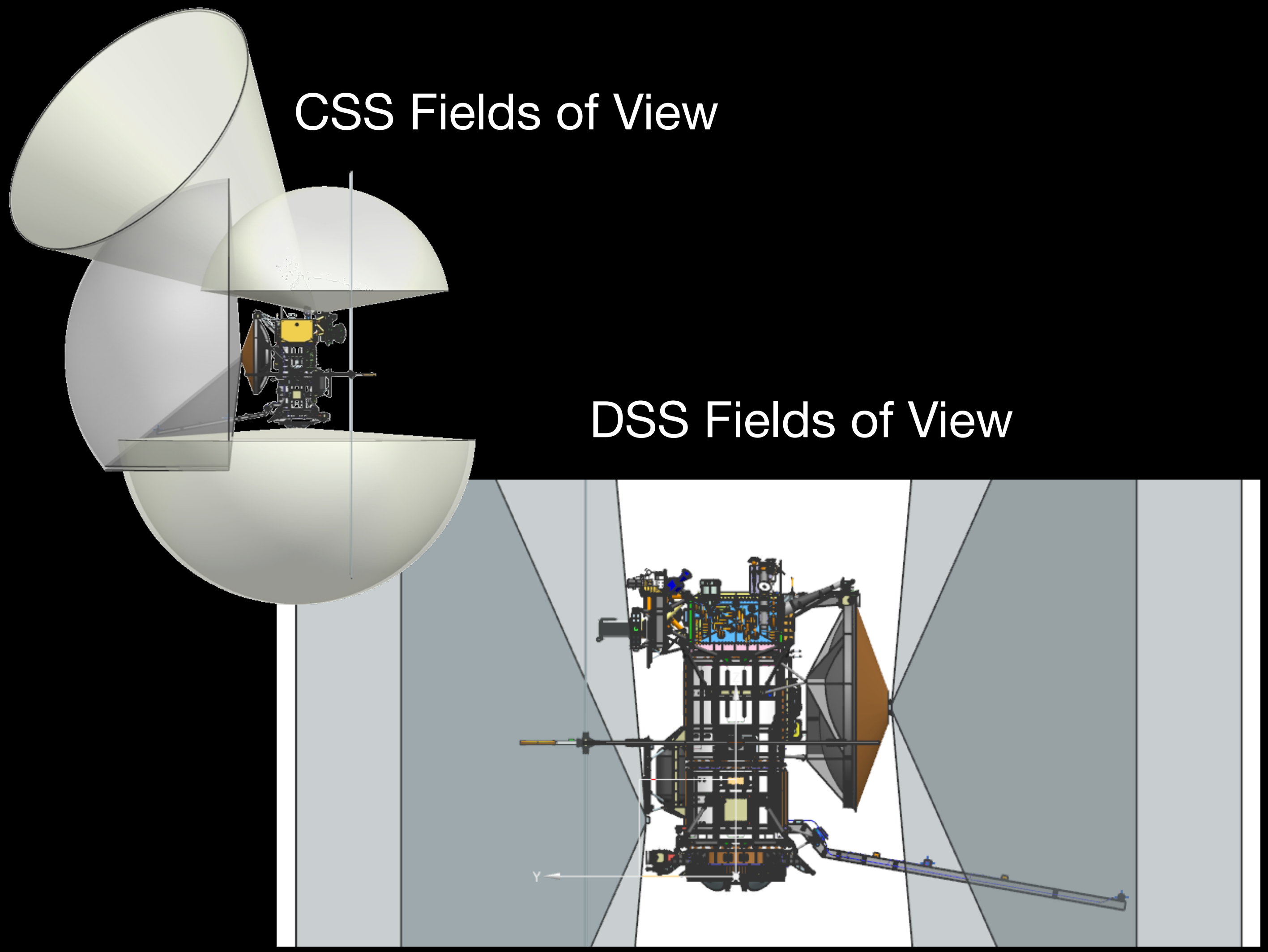
Thermally protected
Antenna position known for telecom
Safely generate power

What is CSS? PV cell that detects sun direction (generates current).
Complexity = sun detected on multiple cells; robustness to loss of cell

DSS = angle determination done in single unit (row of solar cells)

Problems with CSS: couldn't get needed accuracy for base comms rates (& threat of not meeting sun point accuracy needed for thermal safety); not tolerant to albedo (tricked by bright bodies)= inhibit sun search in flyby; sun search algorithm complicated due to CSS limitations → software and testing cost & complexity; possibly too slow in worst case

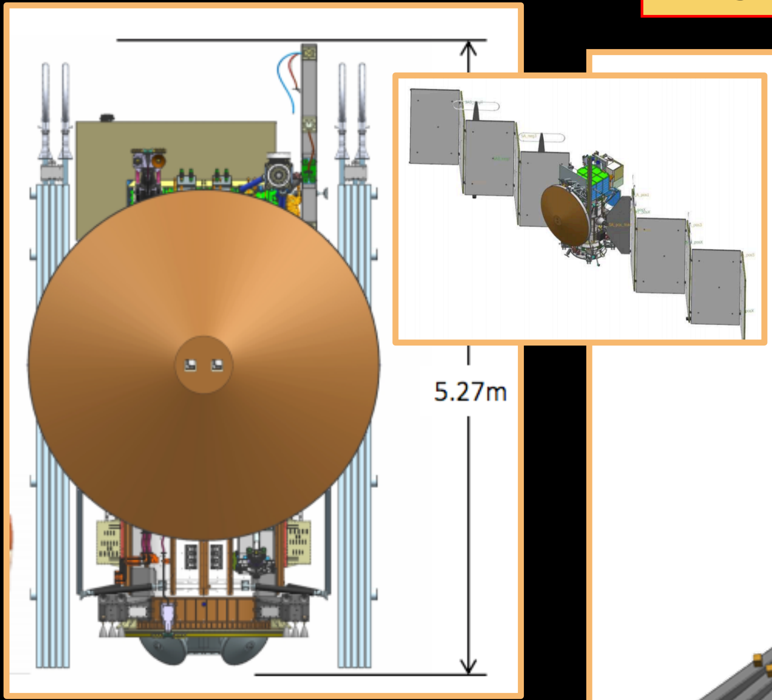
Trade: CSS/DSS (2)



- Slew faster = increased propellant use & unintended delta-v
- Considering compliance by relaxing requirements & constraints (such as increased prop use, less robustness, etc)

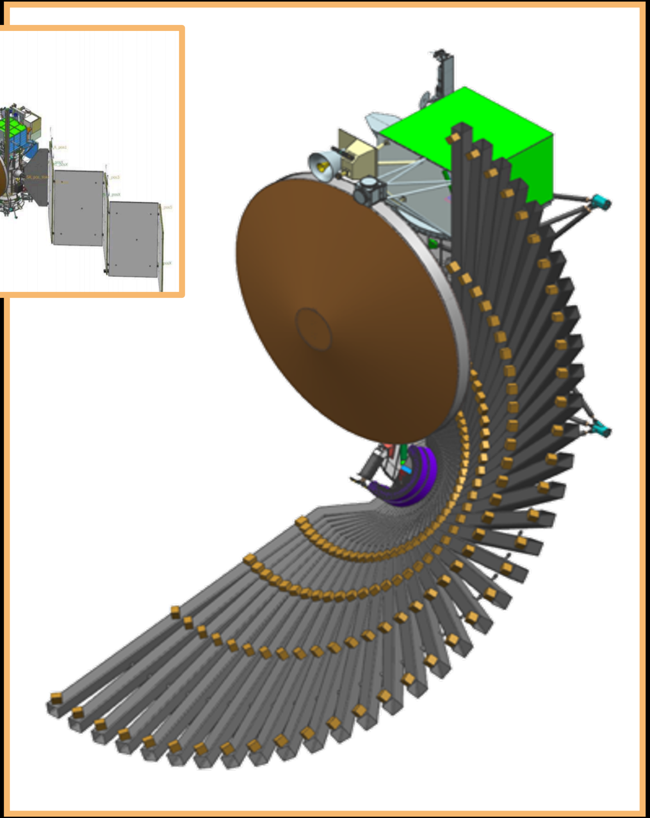
- DSS put system back into requirements compliance & provide margin, robustness to accuracy and sun search duration

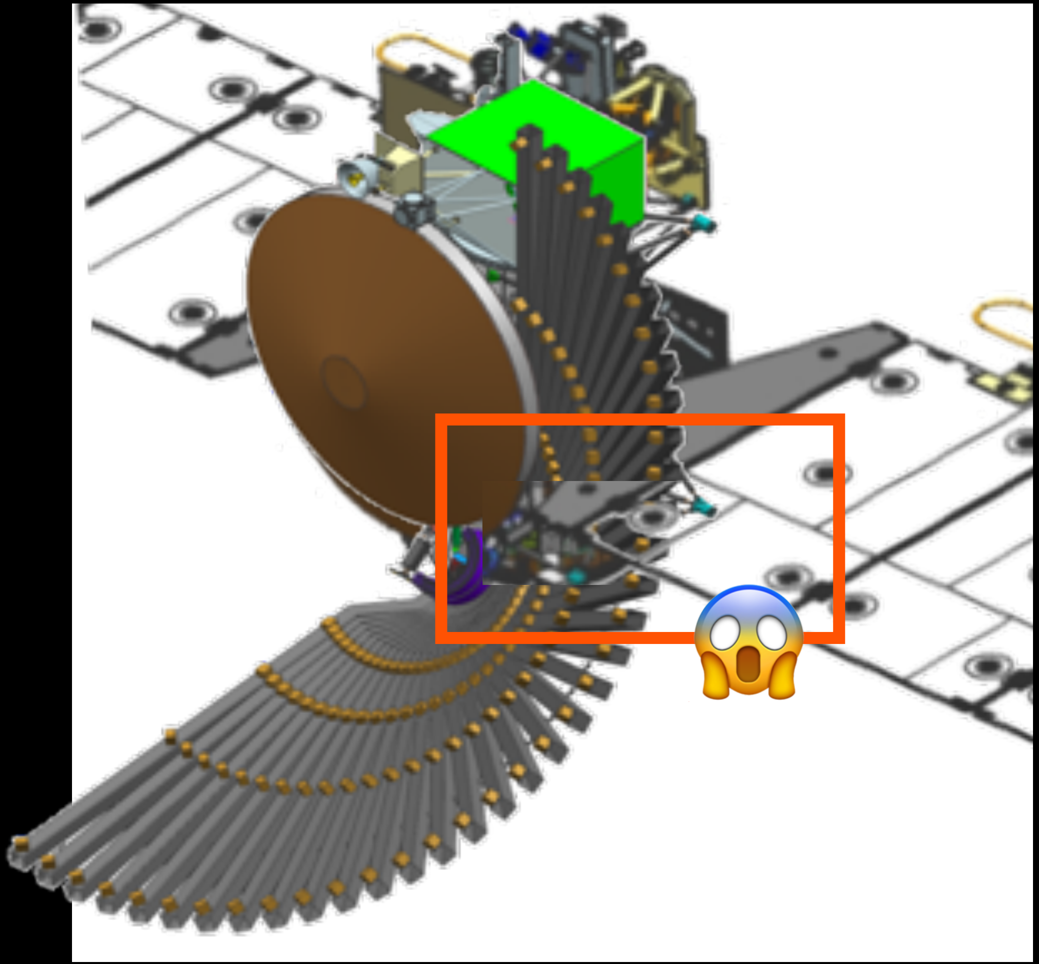
Trade: Magboom Deployment



Magboom Stowed

Magboom Deployment





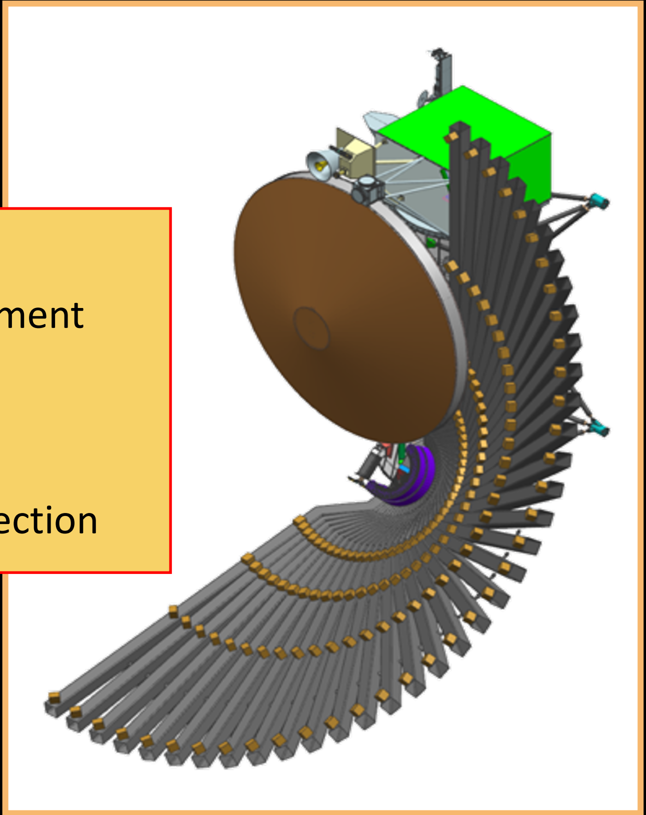
Trade: Magboom Deployment

- Driving concerns:
  - Magboom and SA should never occupy the same space & time
  - Safe deployment (no damage)
  - Visibility into deployment status (especially for fault cases)

- Initial Telemetry:
  - Restraints released
  - Final location reached
  - Health Status

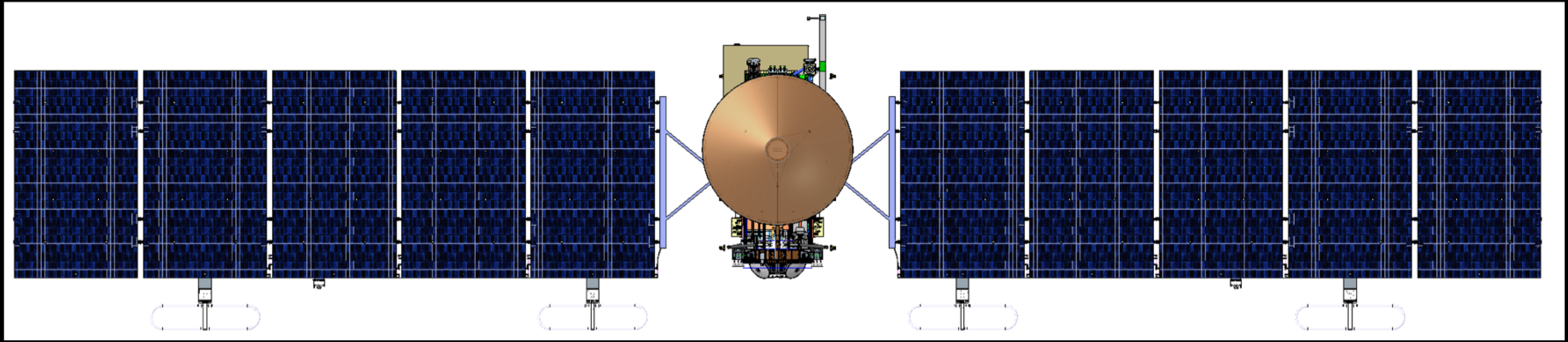
- Improved Telemetry:
  - Restraint release OR assessment of safe to actuate
  - Solar Array articulation region cleared
  - Deployment Completed
  - Boom position (about hinge) within +/- 5 degrees of actual
  - Current & Temperature status

Additional Capabilities:
- If SW resets, stop driving deployment
- Stop deployment if motor stalls
- Survive driving against hard stop
- Ability to drive boom backwards
- Echo back commanded drive direction



Solar Array Make/Buy

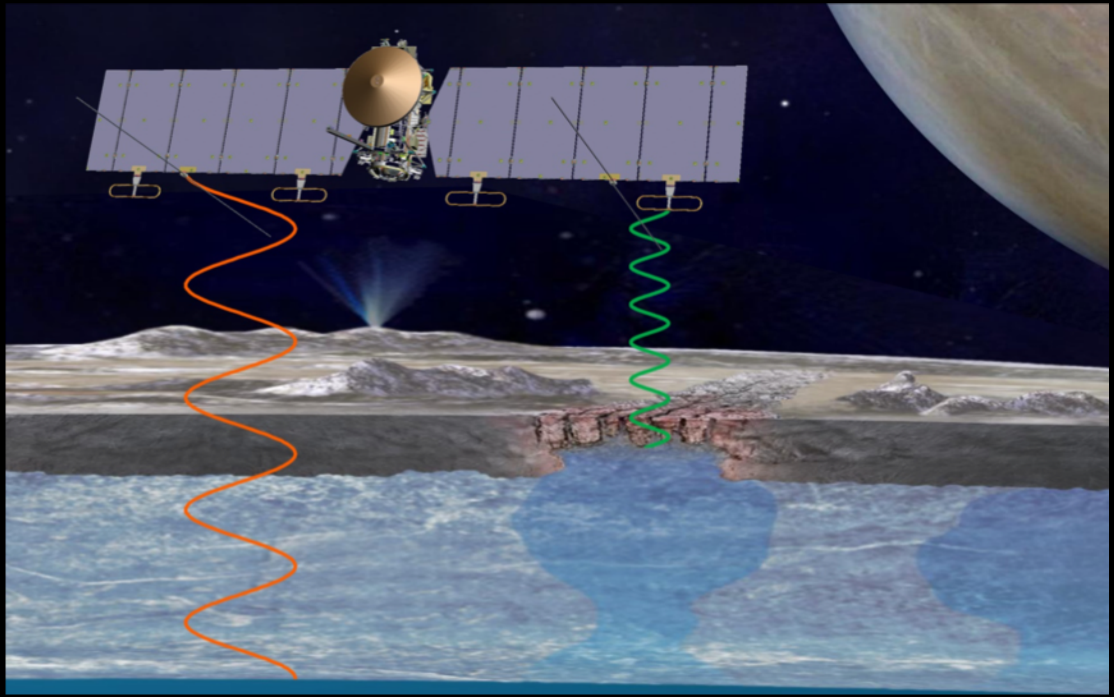
- Was:
  - Make Solar Array in-house
  - Observed delaminations after exposure to radiation and flight-like cryogenic temperatures
  - Investigation consumed schedule and threatened launch date
- Is:
  - Procure Solar Array from Airbus Defense and Space – Netherlands (ADSN)
  - Leverage experience of vendor with specialty in SA systems
  - Leverage recent solar cell and substrate development experience on ESA's JUICE project



REASON Accommodation

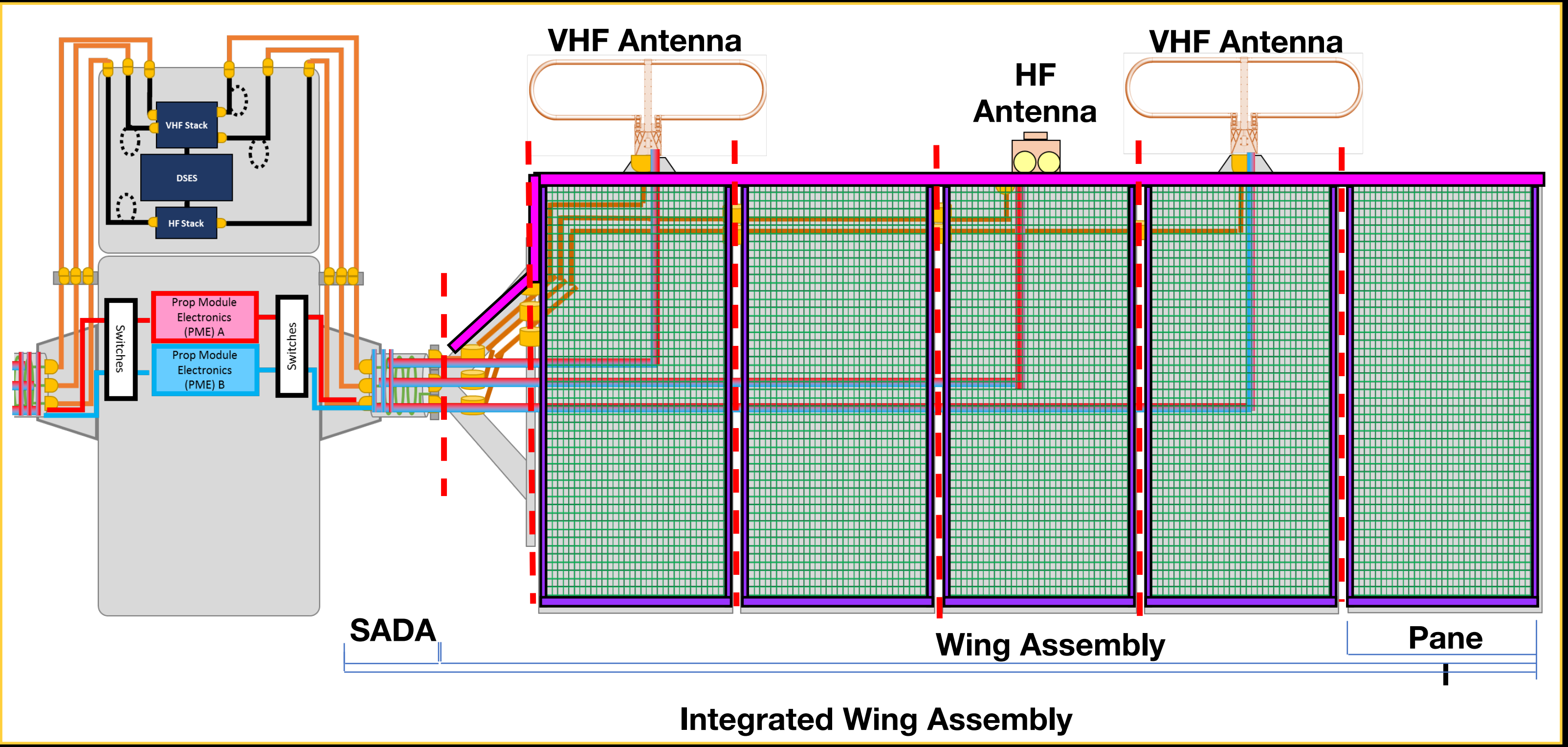
Subsequent Reviews Passed: Proj. PDR, SA PDR, SA Delta PDR, Integrated Wing Review

REASON Accommodation



- Context:
  - Decision made in March 2016 to accommodate REASON on the Solar Array (after trade of many accommodation options)
  - While this is the best option, *it is still very challenging*
- Requirements
  - REASON: sufficiently predictable radar environment for REASON to perform science
  - Solar Array: can deploy and provide sufficient power over mission lifetime
- Review History
- IWR Success Criteria:
  - Design allows REASON to perform measurements necessary to achieve science objectives
  - Design modifications required to accommodate REASON are achievable: no unacceptable risk
  - Preliminary design satisfies requirements
  - Confidence in interface definition and maturation
  - Plans for open items are reasonable

REASON Accommodation Challenges



- Hinge torque
- Edge ground
- Signals through SADA
- Cables
  - Huge thermal range (-238 C to +180 C)
  - Segments
  - Radiation
  - Shielding (when necessary)

IWR

PM CDR

SA CDR

Jan 19	Feb 19	Mar 19	Apr 19	May 19	Jun 19	Jul 19	Aug 19	Sep 19	Oct 19	Nov 19	Dec 19
Jan 20	Feb 20	Mar 20	Apr 20	May 20	Jun 20	Jul 20	Aug 20	Sep 20	Oct 20	Nov 20	Dec 20
Jan 21	Feb 21	Mar 21	Apr 21	May 21	Jun 21	Jul 21	Aug 21	Sep 21	Oct 21	Nov 21	Dec 21

Proj. CDR

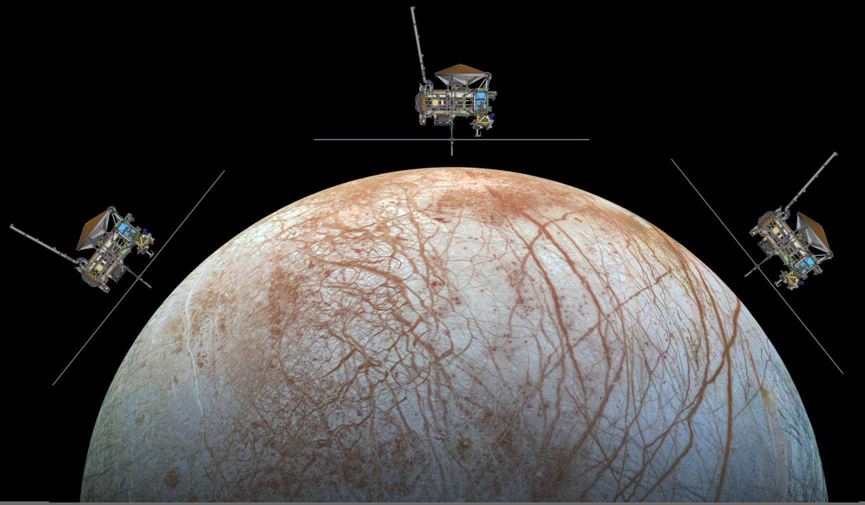
Sys Integr. Review

Start SI&T

Future Work

Future Work

- Power Tiger Team
- Battery Resource Accommodation
- PCDA Accommodation
- Solar Array Side Swap
- Lightning Suppression Design

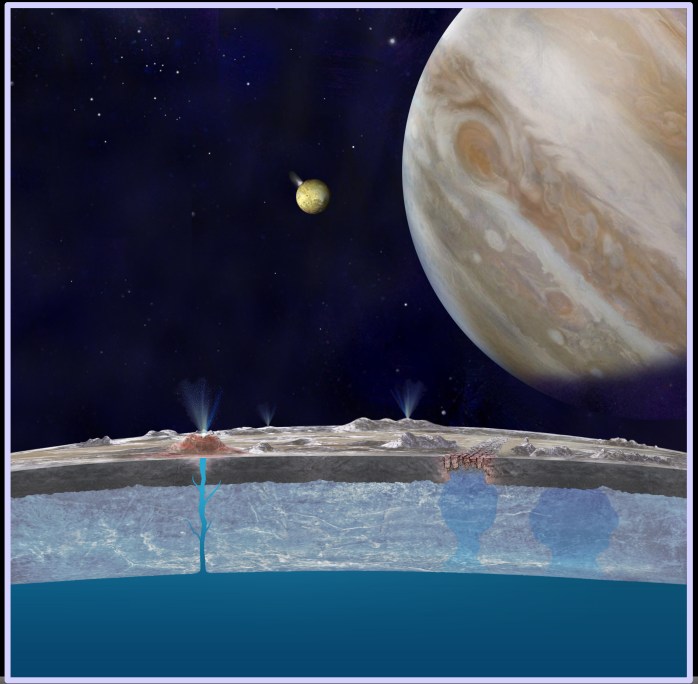


Future Work (2)

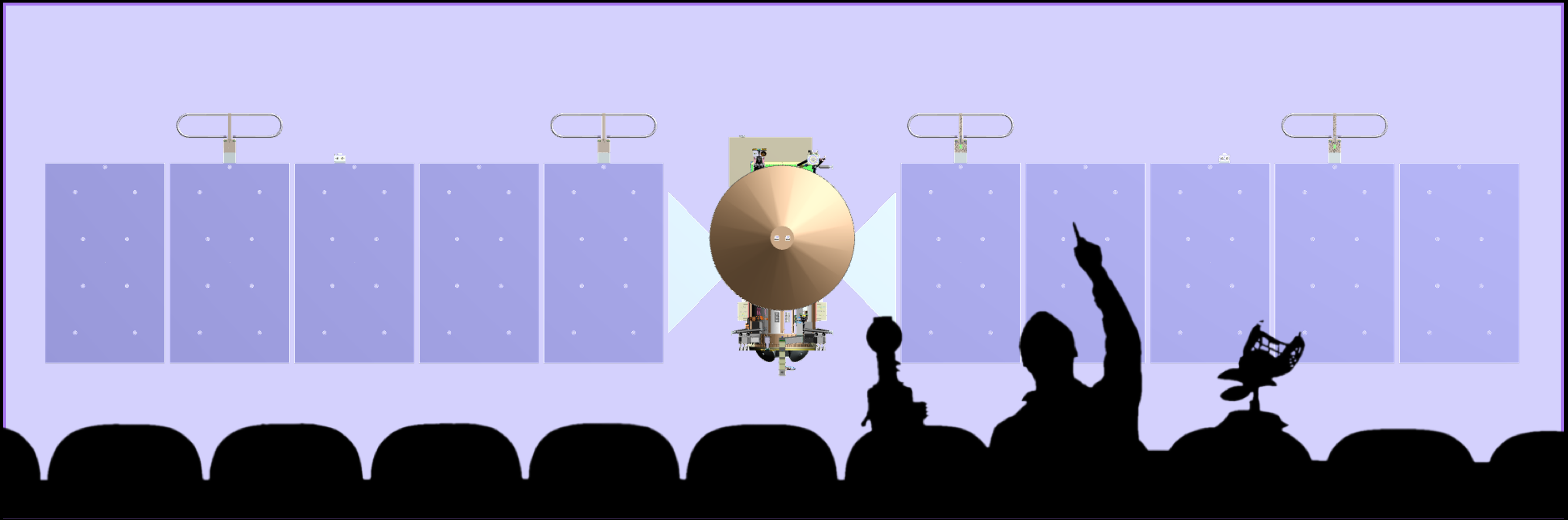
- Reaction Wheel Trade
- ELV & SLS IRD Updates
- SRU Orientation
- REASON Accommodation Requirements Update
- PIMS Charging
- Instrument PRTs for Robustness
- Voltage Drop Updates
- Contamination Control Updates
- Preferential Venting
- Power Allocations Update

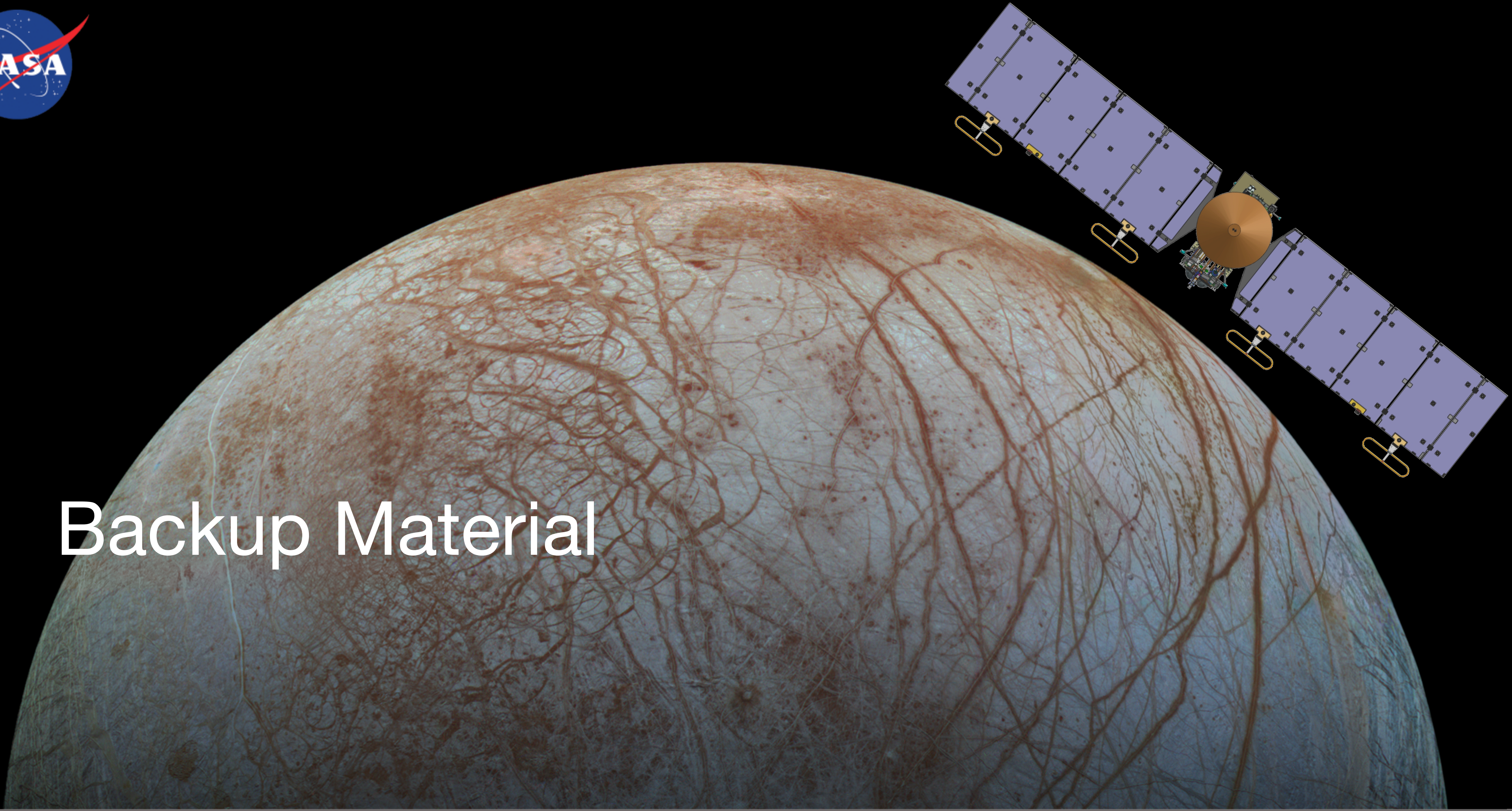
SE & Reviews

- Requirements Scrub
- V&V Ramp-up
- CDR Season



Questions?

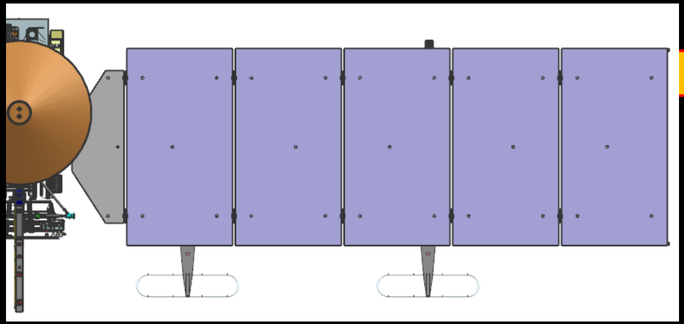


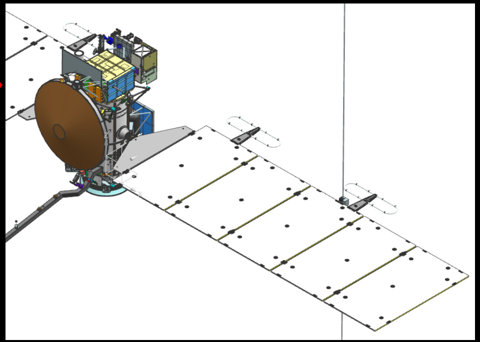


Backup Material

REASON / Solar Array Integration

SRR/MDR (Jan 2017) Baseline ("A5")

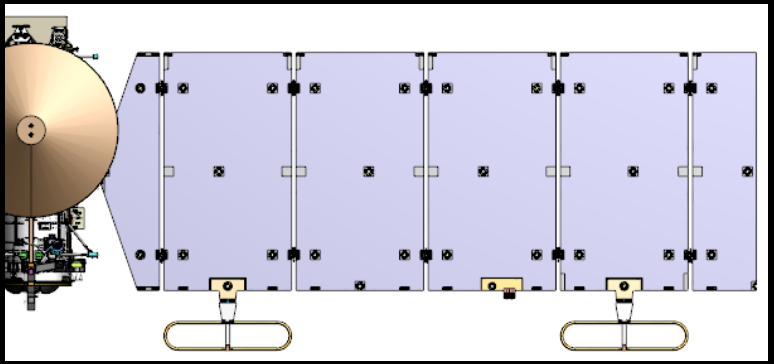




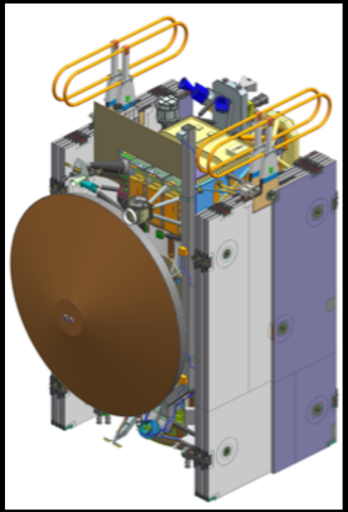
What: HF antenna moved to same side as VHF antenna
Why: Reduced complexity/mass of launch restraint architecture

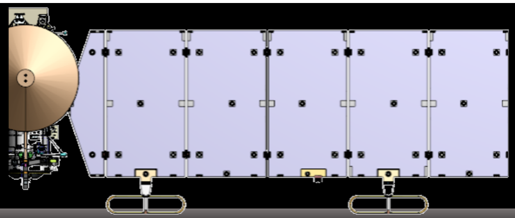
New issues: unacceptable stresses on SA; need to reduce SA mass and inertia

FS PDR (Oct 2017) Baseline ("A7")



- What: HF and VHF antenna spacing updated (VHF must be in center of panel; HF near center of panel)
- What: SA 5 panel → 4.5 panel
- Analysis: science, stresses, keep-out-zones

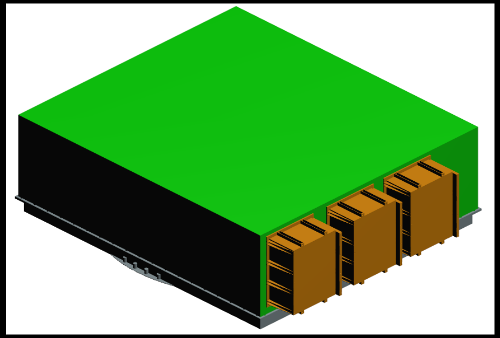




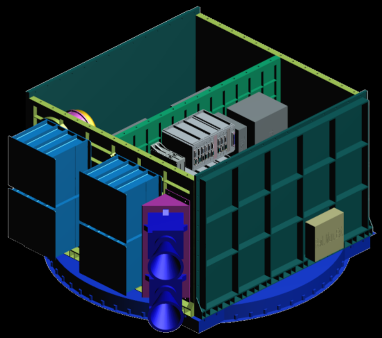
5-Panel Solar Array Compatibility
Cells on Yoke

- Further work on interface properties:
  - cabling on SA
  - Solar array edge ground feature
  - Conductivity/resistance constraints
  - Loads, mass, other dynamics

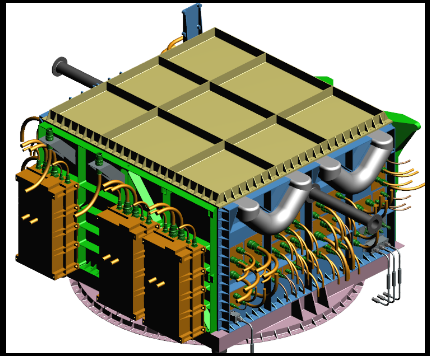
Vault Configuration



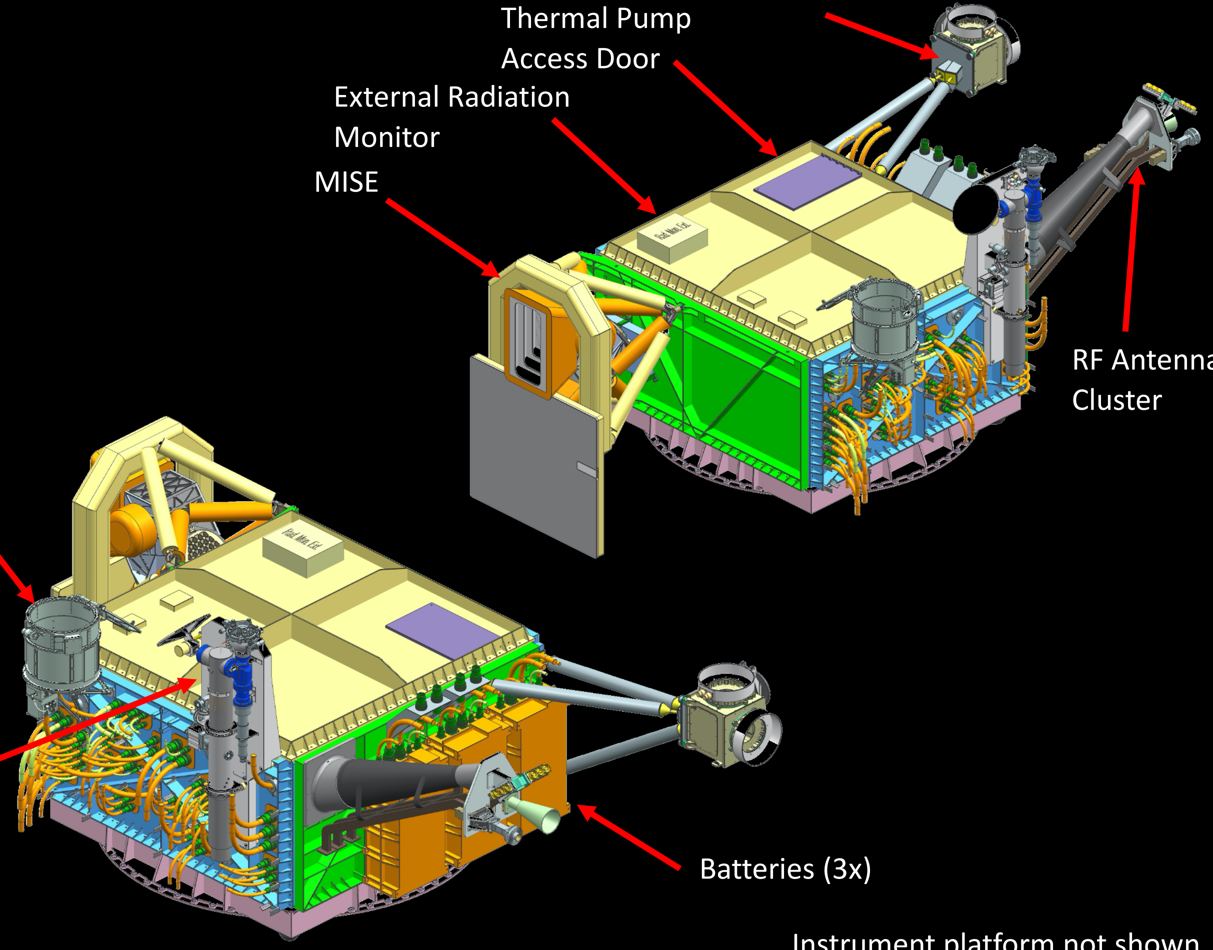
“Pancake” Vault



Center Panel Vault



“+/-Z” Vault

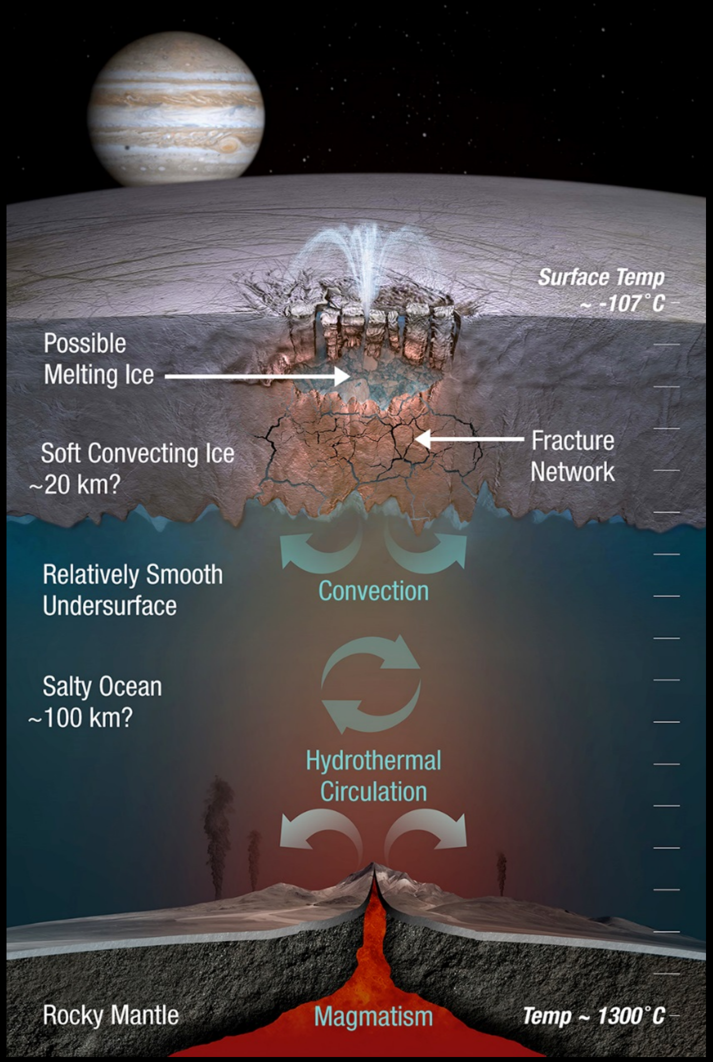


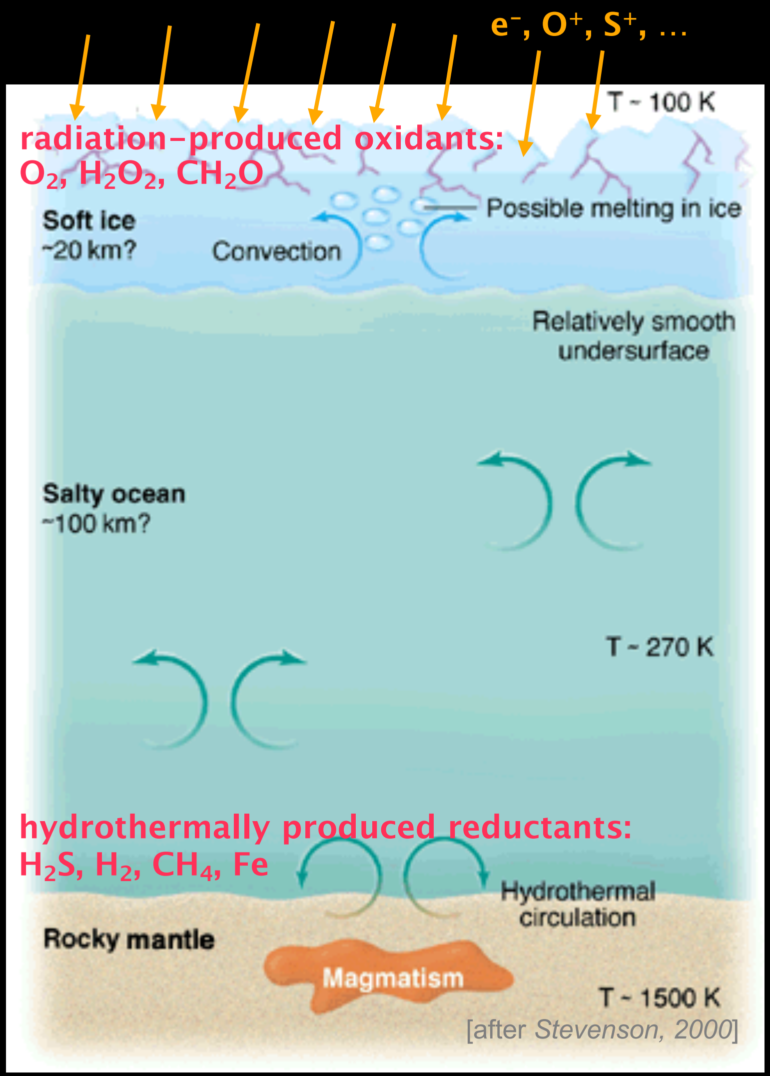
Instrument platform not shown
Instrument covers shown open

Europa: Ingredients for Life?

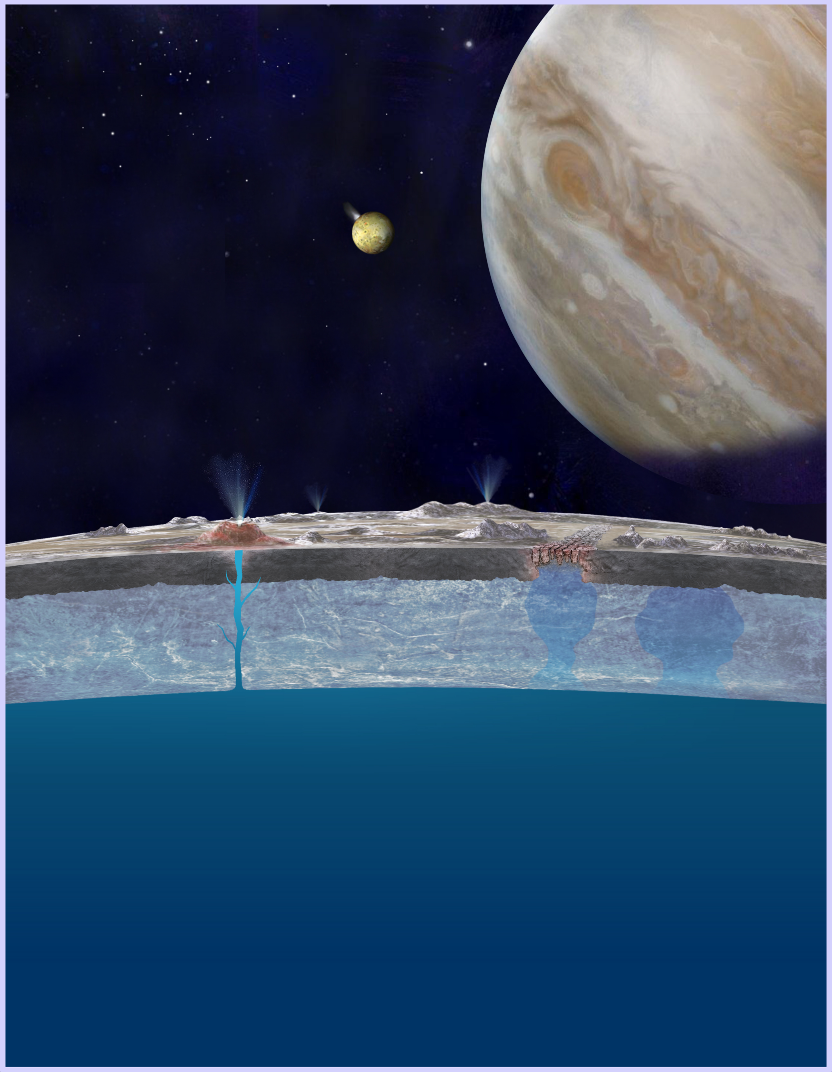
- Water:
  - Probable saltwater ocean, indicated by surface geology and magnetic field
  - Possible lakes within the ice shell, produced by local melting
- Chemistry:
  - Ocean in direct contact with mantle rock, promoting chemical leaching
  - Dark red surface materials contain salts, probably from the ocean
- Energy:
  - Chemical energy could sustain life
    - Surface irradiation creates oxidants
    - Mantle tidal heating could create reductants
  - Geological activity would "stir the pot"

The planned Europa mission would test habitability hypotheses

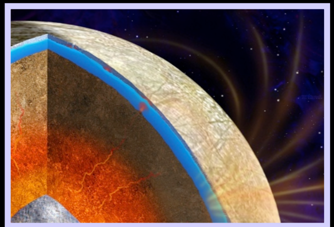


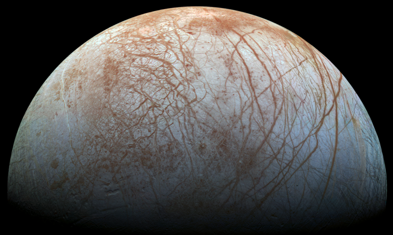


What are we looking at?



- In Situ investigations:
  - Detect and analyze composition of Europa's thin atmosphere
  - Detect and analyze particles originating on Europa's surface
  - Measure magnetic fields
  - Measure density, flow, and energy of ions and electrons
- Remote Sensing investigations
  - Look below the surface (*ice shell and ocean sounding*)
  - Image the surface
  - Locate and characterize plumes
  - Analyze composition of surface (*organics, acid hydrates, salts*)
  - Search for thermal anomalies (*plumes, venting, resurfacing*)
  - Assess possible landing sites (*for potential future mission*)



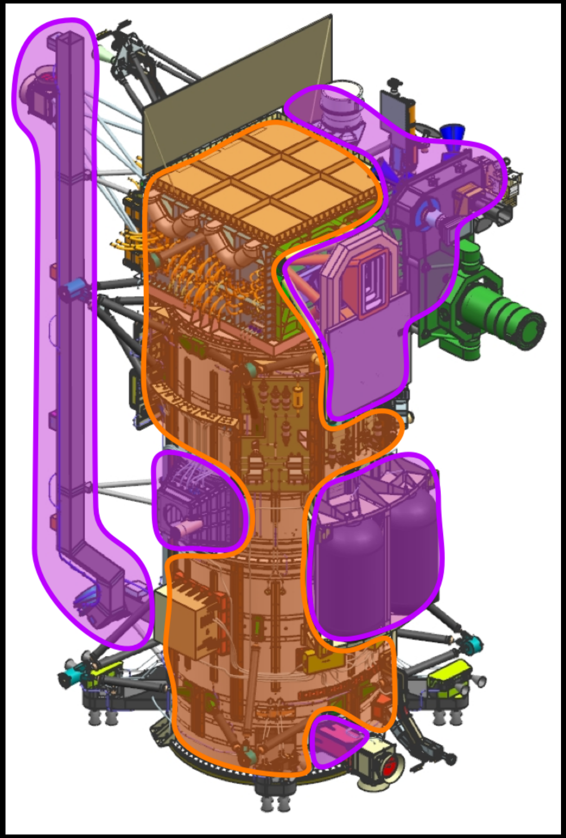
Thermal System Architecture

- Thermal Challenge: minimize energy usage at Jupiter; survive hot inner cruise

- HRS (orange)
  - "R" = rejection, reclamation, reuse
  - Reuse dissipation heat from vault to heat Prop components
  - Pumped fluid loop + replacement heater block
  - Thermal Radiator
  - Covers majority SC components

- Active thermal control (purple)
  - For non-loop elements
  - Instrument interfaces (majority)
  - Some propulsion components
  - Sun sensors, solar array deployment components, radiator, etc

- Passive control (blankets, coatings, etc)

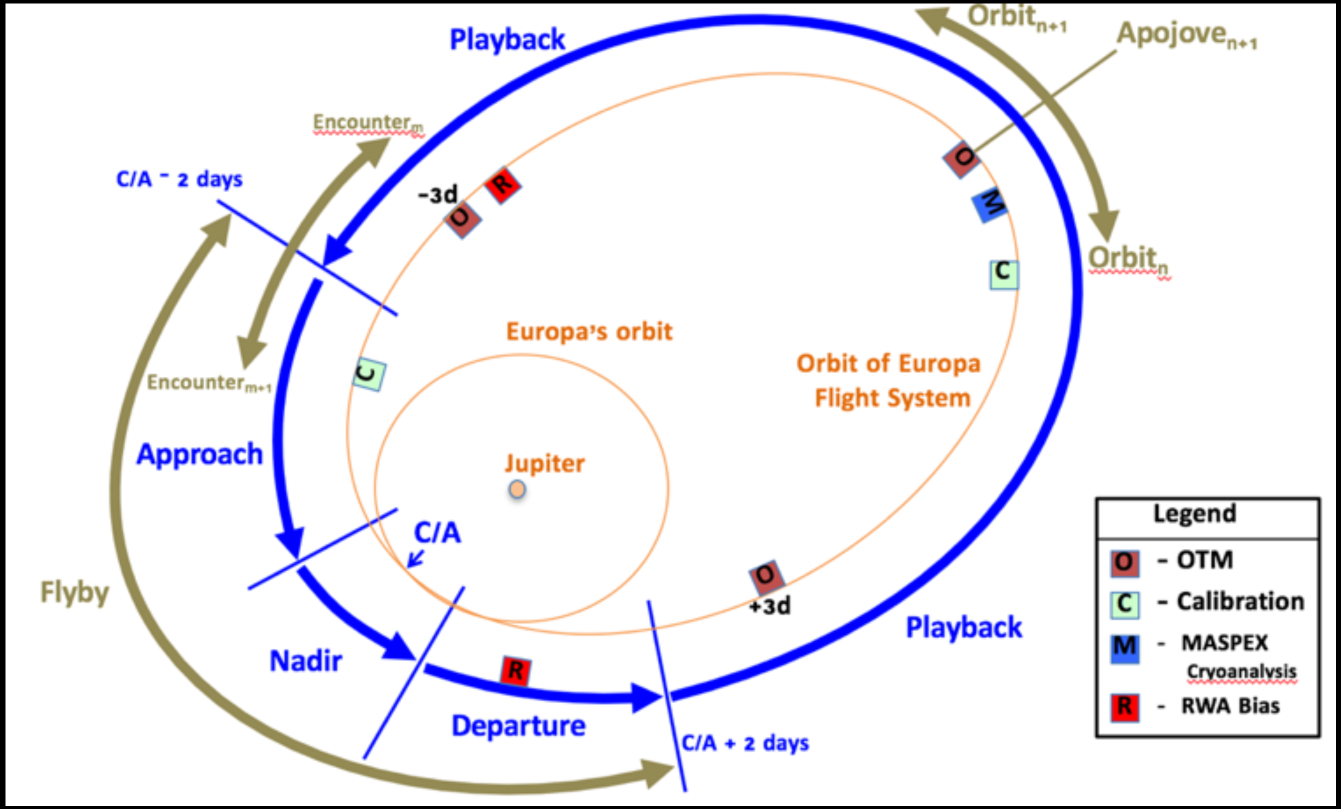


Concept: thermally isolated zones controlled with traditional closed-loop or thermostat heater circuits

Not shown:
- Solar Array Hardware
- Thermal Radiator
- REASON (on SA)

This is a cartoon sketch to illustrate the HRS/active concept

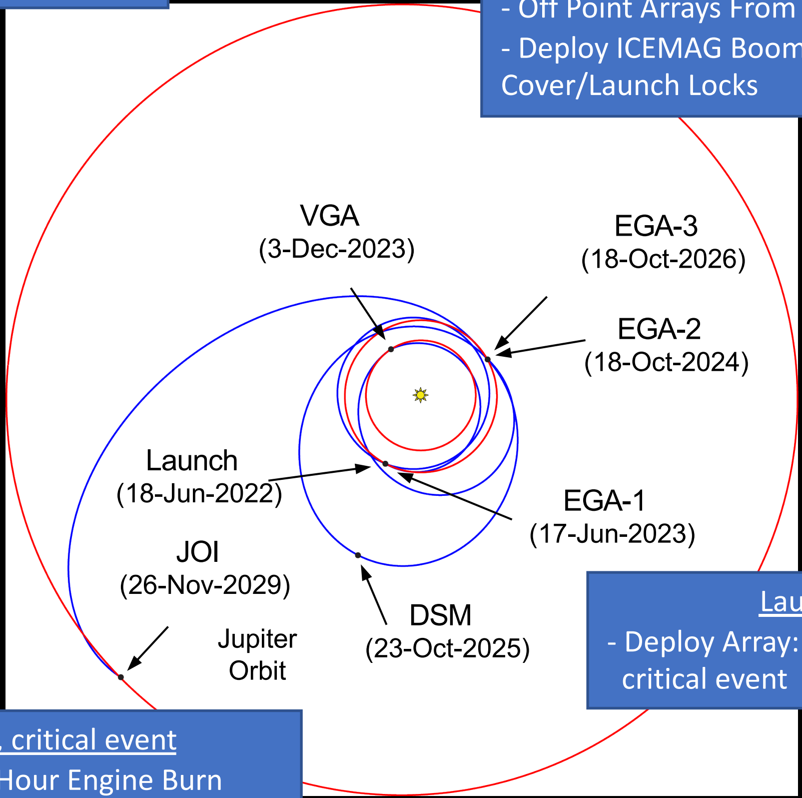
Phases of an Encounter



Operating Modes During Mission Timeline

Outer Cruise
- Instrument Calibrations
- TCMs, RCS Control
- Sun Point Arrays

Inner Cruise (Option)
- Sun Point HGA
- Thermally Limited Off Sun Activities
- Off Point Arrays From Sun
- Deploy ICEMAG Boom, Instrument Cover/Launch Locks

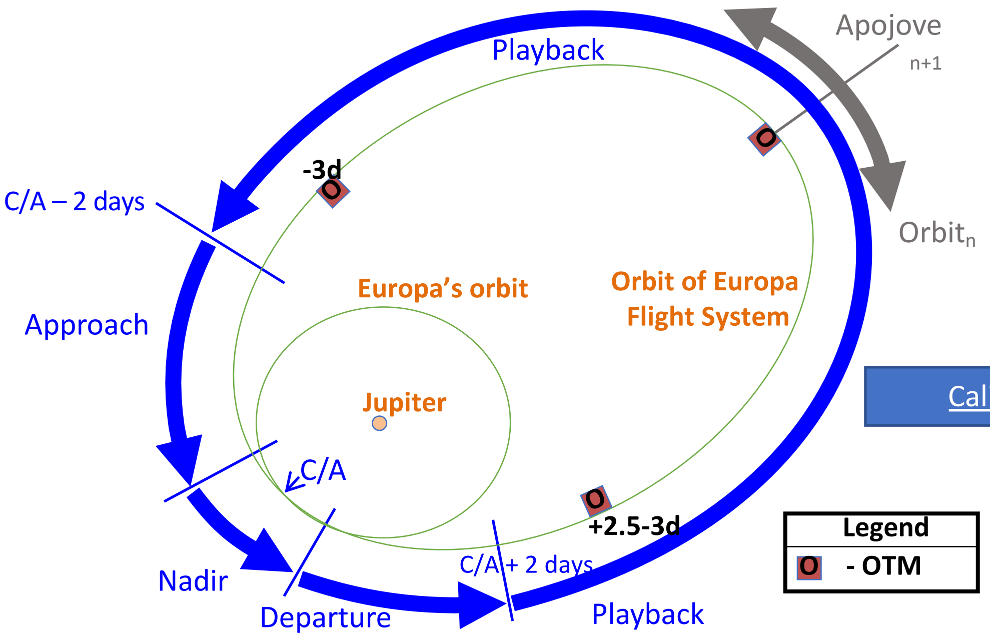


Launch
- Deploy Array: Sun Point, critical event

JOI, critical event
- 5.5 – 6.5 Hour Engine Burn

Encounter Period 10-14 Days

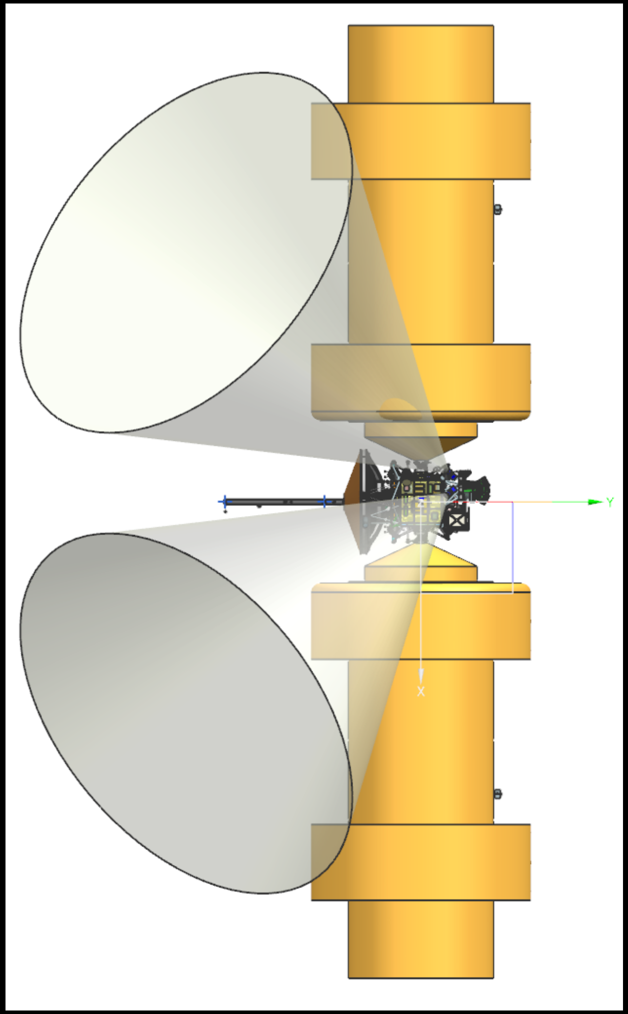
Science Playback



Calibration

Europa Flyby
- Nadir Point
- Closest approach 25km to 2500 km

SA Updates: Impacts



SRU / SA Gimbal Envelop (Inner VHF Antenna)